

ENERGY LABORATORY  
INFORMATION CENTER

PROGRESS ON ANALYSIS OF THE WORLD OIL MARKET

by

Members of the M.I.T. World Oil Project

Working Paper No. MIT-EL-75-015WP

October 1975



PROGRESS ON ANALYSIS OF THE WORLD OIL MARKET

A Six-Month Report

To The National Science Foundation

On The Project "Analysis Of The World Oil Market"

Contract No. SIA75-00739

Prepared By

Members Of The M.I.T. World Oil Project

Energy Laboratory

Massachusetts Institute of Technology

October 1975



## PREFACE

In the summer of 1974, a project on "Analysis of the World Oil Market" was initiated by the M.I.T. Energy Laboratory in association with the M.I.T. Sloan School of Management and the Department of Economics. Over the early months of activity, the project was sustained at a modest level of effort by Energy Laboratory internal funds. A three-year research project was proposed to the National Science Foundation, and in March 1975 a grant was awarded (Grant No. SIA75-00739) for the first 18 months of this period. This paper is a report on progress after the first six months under the NSF grant, and a discussion of planned directions of work over the months to come.

As anticipated at the time the grant was requested, the research is being carried out under the supervision of Professors Henry D. Jacoby (Principal Investigator), and Robert S. Pindyck, M.A. Adelman, and Zenon S. Zannetos (Co-principal Investigators). In addition, the project has benefited from the participation of Professor Martin Weitzman, Dr. Maureen S. Crandall of the Energy Laboratory Staff, and Dr. Paul L. Eckbo, formerly a graduate student in the Sloan School and now a participant in the project through a joint agreement with the Center of Applied Research of the Norwegian School of Economics and Business Administration. The research on financial implications of the world oil market, which was not included in the original grant proposal, has been supervised by Professor Donald R. Lessard of the Sloan School and Dr. Tamir Agmon, a Visiting Lecturer at M.I.T. from the Graduate School of Business, Tel Aviv University. The financial work has continued to be supported in part by internal Energy Laboratory funds.

Over the first six months of the project, six graduate student assistants and two undergraduate assistants have participated in the research.

## OUTLINE

	<u>Page</u>
1. Overview of the Research Design	1
1.1 The Overall Analytical Framework	3
1.2 Two-Part Analysis	4
1.3 Modular Construction of the Simulation Model	6
1.4 Market Clearing Processes	10
2. Demand Analysis	15
2.1 Data Development	15
2.2 Plans for Estimation	18
2.2.1 Residential Demand	18
2.2.2 Industrial Demand	21
2.2.3 Transportation Demand	21
2.2.4 Commercial and Other Demands	21
2.2.5 Energy Transformation	22
3. Supply Studies	24
3.1 Supply Model Design for Price Takers	25
3.2 Data Development and Supporting Analysis	31
3.2.1 Capacity Estimates	34
3.2.2 Costs	35
4. Study of Market-Clearing Processes	44
4.1 Behavioral Models of OPEC Pricing	46
4.1.1 Dynamic Optimizing Models	48
4.1.2 "Story-Telling" Exercises	53
4.2 Transportation and Refining	56
4.3 Financing	59
5. Revised Work Schedule	62
References	71

## 1. OVERVIEW OF THE RESEARCH DESIGN

The evaluation of U.S. energy policies is strongly affected by analyses and judgments about current and expected trade patterns in the world oil market, and the associated oil price. At present, U.S. domestic energy prices follow the world price, and thus developments in this market play a dominant role in the consideration of measures to stimulate domestic supply or encourage conservation, and in discussion of the difficult areas of oil and gas price controls, energy taxation, public utility regulation, and anti-inflation policy. Further, because of its significance for the domestic economy, important issues are raised about measures to buffer the country from the vagaries of the market--by means of tariffs and quotas, or through security measures such as crude oil stockpiles.

The oil price itself also plays a major role in the planning and implementation of the national energy R,D&D program. The financial and economic implications of programs of "commercialization" of new technologies--be they possible schemes of direct subsidy, or various forms of loan guarantees--are directly influenced by the expected price for which the energy can be sold. In the case of a technology that may be commercially exploitable within a reasonable time period given some federal assistance at the outset, the world oil price determines the level of risk that may have to be borne by private and public sources. For a technology which may not be commercially feasible in the next decade or two but which may be granted a long-term subsidy for reasons of broader national policy, the world oil price is a key determinant of the level of financial commitment which the federal government must make.



Given the importance of the international oil market for domestic policy deliberations, our understanding of the way it functions and our ability to analyze potential future developments are woefully poor. The purpose of this research project is to improve the methods of analysis and supporting data that are available for this important task.

The focus of the effort is on the actions of the oil cartel as it attempts to manipulate prices and quantities in the market, and on the forces of supply and demand that influence the ability of the cartel to sustain any particular price strategy. The "market" in this instance can be seen as comprised of three elements:

- (1) Importers. There is a set of petroleum importing countries, dominated by the industrialized economies of the U.S., Europe, and Japan. The oil import demand of each of these countries is determined by their total energy demand, less the domestic supplies available, and less imports of other fuels.
- (2) "Price-Taker" Suppliers. There is a group of petroleum exporters who appear to act as "price-takers" in the sense that each takes the world price (which is being set by others) as given and makes supply decisions according to his own parochial interest. They do not adjust production plans out of concern for the impact they may have on the overall world price. This group includes various non-OPEC sources such as the producers of the North Sea, the USSR, and China, and potentially other countries such as Mexico. An important objective is to see to what extent certain members of OPEC, which have great needs for revenues, may behave like price-takers and follow "expansionist" oil production policies. The most important are Iraq, Indonesia, and Nigeria.
- (3) The Cartel Core. There is a small group of Persian Gulf nations who form the core of the cartel and who are the "price-makers" in the terminology used earlier. This group includes Saudi Arabia, Kuwait, and others in the Gulf; under some definitions it also may

include Libya, Iran, and Venezuela.<sup>1</sup> These countries face a residual demand for world oil, which is the total demand less that supplied by the fringe of price-taker exporters.

The result of this set of circumstances is a dynamic interplay among these conglomerations of importers and supplies wherein prices are set by the cartel core, and an attempt is made to control oil production so it does not outstrip the world demand forthcoming at that price. The resulting price and quantity patterns, and expectations about their evolution in the future, have a dominant influence on the energy plans and problems of most nations.

As the result of our first six-months of work on this market, most aspects of the analytical approach (many of which were proposed at the outset) have been decided. Sections 2, 3, and 4 of this report summarize the work to date in the different areas, and outline the planned research program over the months to come. In Section 5, a more detailed task-by-task work schedule is presented. To set the stage for discussion of details of the work, it is well to summarize the major aspects of our research design.

### 1.1 The Overall Analytical Framework

Given the state of our knowledge of this market, the building of a data base, estimation of empirical supply and demand relations, and study of the internal mechanics of the market clearing process are judged to be more important than the elegance of the mathematical structure used to tie

---

<sup>1</sup> It is important to notice the vagueness of our statement about where certain countries belong in this simple taxonomy of participants in the oil market. The orientation and behavior of these countries, though poorly understood, is critically important for the stability of the cartel. Study of the implications of the various possible coalitions, therefore, is a key element of our research.

all these pieces together. Thus heavy emphasis is put on demand studies (Section 2), analysis of cost and supply functions for key oil exporters (Section 3), and the study of the determinants of the structure of prices and buyer-seller flows in the market (Section 4).

In keeping with this emphasis on the underlying forces in the market, our initial framework for integrating these components into a coherent market study is based on what we call a "bathtub" approximation to the world oil market. That is, the market is treated as a single pool where exporters put oil in and importers draw it out; the details of the transportation network and of the refinery sector are treated in a drastically simplified manner. More complex mathematical representations of these subsectors will be added only as absolutely necessary, for they usually impose severe limits on the formulation of supply and demand relations and they greatly increase the sheer computational load while (with a couple of important exceptions to be noted below) contributing little to the understanding of larger changes in the market.

## 1.2 Two-Part Analysis.

The basic issues under study here can be boiled down to two interrelated questions: (1) What is the likely path of the overall level of prices which the cartel is likely to try to establish over time, and (2) What are the details of import demand, price-taker supply, and resulting net demand for cartel oil given a pattern of expected oil prices? A forecast of these two aspects of the market then provides a conceptual and empirical foundation for studies of the details of the likely market developments such as patterns of trade, the relative difficulty of cartel discipline, and the likely stability or instability of the market price.

Naturally, the answers to these two questions are highly interdependent, but for analytical purposes it proves very convenient to separate them at first and handle each with a different model structure. The reason for decomposing the problem in this manner is the following: The determinants of importer demand and price-taker supply are varied and complex and involve not only matters of cost and price but very important effects of the tax and regulatory policies of different countries. For analysis of the likely response of the market to one or another price pattern, there is need for a model structure that can accept rather complex or unwieldy functional relationships. This requirement leads naturally to a simulation framework for the overall analysis of market demand and supply outside the cartel. On the other hand, analysis of the cartel itself, and its pricing decisions, may require various forms of static or dynamic optimization calculations. For this part of the analysis what is needed is drastically simplified supply-demand relations so that many formulations of cartel behavior may be simply and cheaply tested.

One might like to analyze the overall problem simultaneously, combining in one calculation the full richness of supply and demand relations over time and the analytical formulations of cartel behavior. However, our work to date has led us to believe that at worst this is computationally infeasible, and at best it would be an unwise approach to research on this issue. Therefore, we have adopted a two-part or "two-model" approach where we combine our supply and demand studies into a "numerical laboratory" which can be used to analyze alternative hypotheses about cartel behavior (this model is elaborated in Section 1.3). The price scenarios or simple heuristic pricing rules input to this model will result from separate, smaller models designed to study the cartel itself (see Section 4.1 below) or from subjective judgments about what is likely to take place.

### 1.3 Modular Construction of the Simulation Model

A schematic diagram of the planned structure for the simulation framework is shown in Figure 1. Each of the rectangular boxes in the figure represents a "module" of the overall calculation. It is our plan to construct this framework in such a way that the whole apparatus can be put together at the outset, perhaps with some very primitive functions and logic in some of the boxes or "modules." But the model is being designed so that better empirical estimates and more satisfying logic can be inserted as the research progresses, simply by replacing old modules with new ones.

The heart of this "numerical laboratory" is the two boxes in the middle, which contain the functions for price-taker supply and import demand. For each importing country there will be a demand sub-module, prepared as part of the demand studies discussed in Section 2. Once the overall framework is constructed, we will insert very simply functions for each country based on OECD data or other sources, or applying a judgment about price and income elasticity. Some experience in this area has already been gained through the first-stage simulation experiment constructed by Eckbo [3]. As the demand analysis proceeds, the primitive estimates will be replaced, and the quality of the overall results upgraded.

Likewise, there will be a supply sub-module for each price-taker supply region, constructed as a result of the studies discussed in Section 3. Once again, we will begin with very simply functions for these suppliers and upgrade the module as the empirical work proceeds.

As noted previously, our initial simulation model will be a "bathtub" approximation, where transport and refinery activities are greatly simplified. It is not possible to abstract completely from these components of the market, however, for they determine the relationships among the prices of crude oil

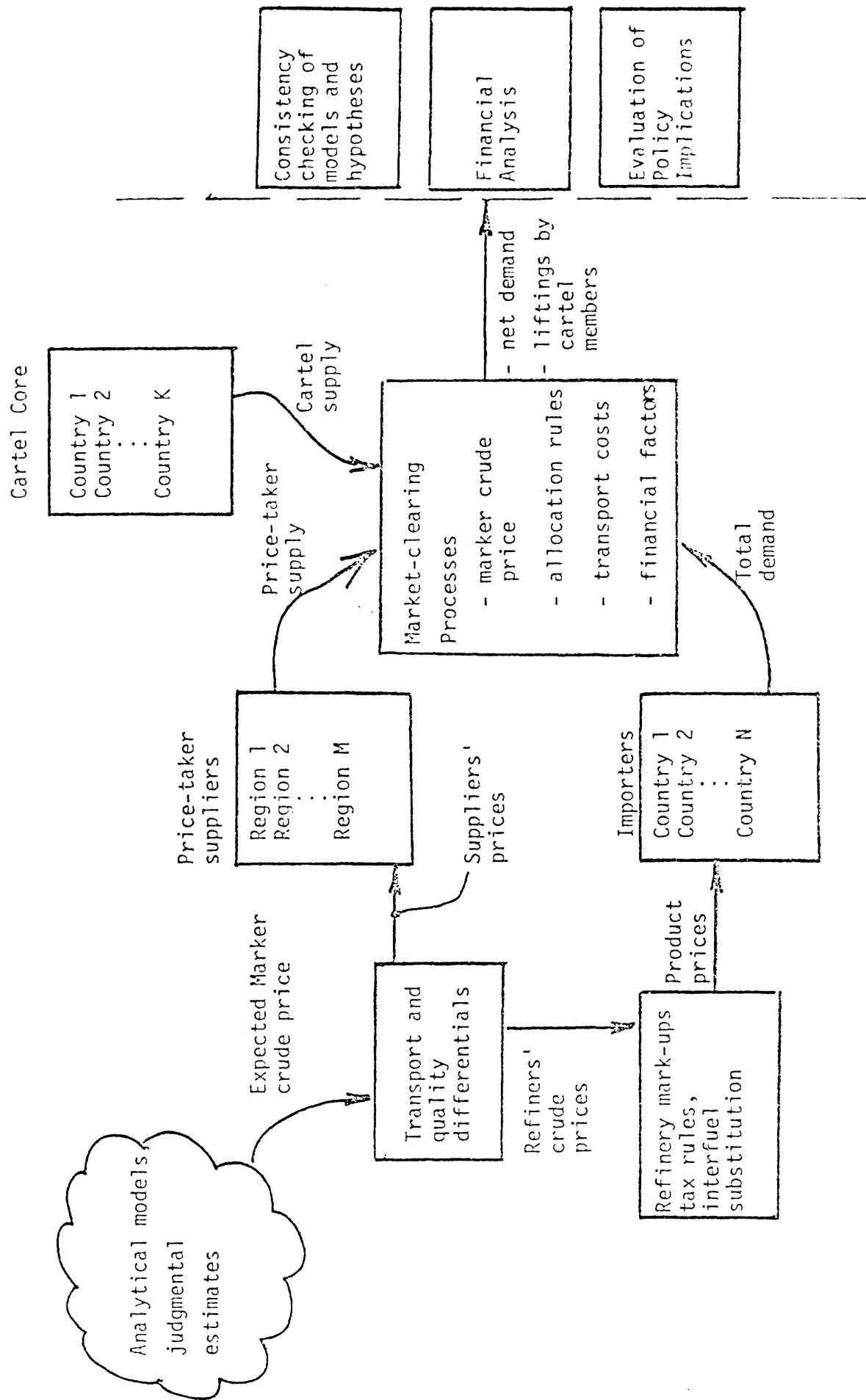


Figure 1. Overall Simulation Framework

in different parts of the world, and between the price of crude oil and the prices of refined petroleum products and completing forms of energy (e.g., coal and natural gas). The two modules to the left-center of the figure provide the necessary linkages. The expected price pattern, which comes from outside this model,<sup>1</sup> will be stated in terms of some "marker" crude, say Saudi Arabian light. This must be converted into the relevant crude oil price pattern at each of the supplier regions and importing countries. At the outset, this will be done with a simple matrix of transport costs based on the two to three year time-charter rate (see Section 4.2).

By the same token, the crude oil price to each importing country must be converted into a set of product prices, for the demand equations will be estimated in terms of the prices of fuel oil, gasoline, kerosene, etc. At the outset, this will be done with a simple relationship for refinery margins, taking account of the excise tax policies of the various consuming governments. More complex calculations can be devised for this module, as with transport, but a decision to do so will await experience with the simpler formulation. In addition, the demand equations require forecasts of the prices of coal, natural gas, and electricity which are influenced by oil price, but of course are also affected by a number of other factors. Once more, complex functions can be devised for this price relationship, but at the outset this module will contain only a very simple calculation, very likely based on the concept of BTU equilibrium with special corrections where regulatory and tax considerations intervene.

---

<sup>1</sup>For simplicity, we speak here as if the price vector is completely exogenous to the simulation model. In fact it will be possible to construct simple pricing rules that make price endogenous so long as those rules do not involve complex manipulation of the supply and demand modules.

The results of a calculation of total price-taker supply and total import demand are then inputs to analysis of the market-clearing mechanism and study of the likely problems of cartel stability. That is, who among the cartel members will produce the oil to meet this net demand, and under what conditions? In the first version of the simulation framework, this calculation may be little more than a calculation of net demand and allocation of this demand among cartel suppliers according to some simple rule in order to show how the market might "clear."<sup>1</sup> But as the work proceeds, more attention will be devoted to this aspect of the market, and perhaps it will be possible to incorporate more of the analysis into the simulation model itself. As discussed below, it is the dynamics of this process, taken in the context of the net demand conditions, that determines the ability of the cartel to set the price according to the members' own perceived interest.

However simple or complex the calculation of the market-clearing process, these results then become inputs to several analysis and interpretation activities as shown at the far right of Figure 1. First, there is the task of evaluating results to check their consistency with the original price scenario used in the estimation of supply and demand, and of iterating this model with the cartel analysis until inconsistencies have been ferreted out. Second, there are a number of financial issues that are raised by any particular forecast of world oil trade, and the output from the simulation becomes an input to such studies (see Section 4.3 below). Finally, there is the matter of interpreting the policy implications of alternative sets of results.<sup>2</sup>

---

<sup>1</sup>For example, this approach is used in our first simulation model prepared by Eckbo [3].

<sup>2</sup>Naturally there are political and military implications of the results, as there are similar influences on the behavior of the key participants in the market. While these factors are not the dominant theme in this research, they are taken into account where we have the capacity to do so.



#### 1.4 Market Clearing Processes

The importance of study of market structure, and the processes by which detailed country prices and quantities are determined, can be illustrated by a brief review of how this cartel-dominated market works. First, note that at any given time various crude oils will have different prices even given a basic cartel or "marker crude" price. The structure of differentials refers to four components: Freight, sulfur content, specific gravity (lighter fractions are more valuable), and "all other" covering a miscellany of which perhaps the most important is suitability for lubricating oil. However, the "all other" is usually quite small and may perhaps be treated as a random disturbance.

Variations in the other three differentials are also small relative to the cartel price, and may safely be neglected in a simple "bathtub model" where the task is to calculate import demand and overall price-taker supply. However, in studying the market-clearing (or market stability) problem faced by a cartel, these differentials and their fluctuation over time are of first-rate importance. At any given time there is a certain pattern of market shares which the cartel members will regard as acceptable, and each of them will have some lower bound below which he will refuse to go. If this boundary is violated, a country may change from a cooperative member to a price-taker, or perhaps even a price-cutter as he strives to redress the balance, for price differentials will affect market shares.

In the long run, gradual shifts in technology (e.g., desulphurizing), tastes (e.g., small cars cutting the gasoline fraction), or growth rates (faster industry growth boosting the demand for residual fuel) will change the amount demanded of a given country's output. If the quantities supplied by each cartel member are fixed, then price relationships must change. If

prices for each type of crude are fixed, then the quantities taken must change. More likely there will be change in each dimension.

Perhaps more difficult to handle are the changes which take place within a year. The sulfur premium can change appreciably, while fluctuations in short-term tanker rates are notorious, and may reach 100% upward or 50% downward of the true long-term rate, even in years of no big outside disturbance like an embargo. The result is that delivered prices fluctuate considerably, and so does the desirability of one or another type of crude to a refiner trying to minimize costs. The impact on the refiner's profit margin may be very large indeed even when the differential is small as a percentage of the delivered crude price.

The problem is compounded by the excess capacity which is characteristic of most cartels, and which is very marked at this time in OPEC. A country whose crude happens to be more desirable can offer very large additional amounts at short notice. There is also some interaction with a relatively under-employed tanker fleet, where the supply of tanker services is very elastic because ships are being operated at low speeds and there is an overhang of ships in port available for service.

If the market-clearing process were left to each country's discretion, then it would probably be impossible to maintain the current price level or anything resembling it. Nobody would know what was the right price to charge. The surplus capacity would shift uncontrollably back and forth. Erosion of a price level generally begins with distortion of the price structure, and loss of control of discounts and extras.

The fact that the cartel members are governments makes the situation easier for them in some cases, harder in others. Loss of sales means loss of budget revenues. Where the country has large holdings of liquid assets

with which to meet its expenses, particularly foreign exchange expenditures, it can hold fast to a given price level. Otherwise, the pressure may be great to increase output no matter what.

But an acceptable realignment of market shares can be accomplished either by governments reducing the customary differentials, or by the standard or "marker crude" (Saudi Arabian light) rising to restore the previous balance. Hence a counter-intuitive result, borne out in October 1975, is that weakness of demand may lead to a higher cartel price. It may possibly be a non-maximizing price for the "inner core" or even for the cartel taken as a whole, but it may be a necessary side payment from the core to the fringe to keep them from acting as real price-takers. This kind of solution is characteristic, since a cartel is a diverse organization which must resort to second best or n-th best solutions.

The market-clearing process is still largely the responsibility or task of the international oil companies. Under the old concession system the profit margins on crude production were sufficiently large to dampen or sometimes prevent altogether any movement from higher-cost to lower-cost crude. A company with one or two large concessions was tied to one or two crudes, and would only have sacrificed profits by switching its crude procurement in response to market prices. The relevant variable was the price of the purchased crude vs. the much lower tax-paid cost of its "own crude." A company with two or more concessions would make a comparison of respective tax-paid costs rather than of market prices. The ultimate decision was left to bargaining with the respective governments, backed up by pressures and veiled threats.

To a large extent this system is still effective, but the degree of effectiveness is one of the chief unknowns we need to investigate. The corporations and the governments are now bargaining over the remuneration of

the resident companies. The bargaining is of course over investment requirements and sources of investment funds, operating costs, management or service fees, etc.; there may also need to be something akin to a "marketing fee" (or some other set of words to describe a price concession) to equalize the attractiveness of the crude to the refining company. The international companies are moving away from producing their "own crude," and de-emphasizing crude production at high profits which will cover possible losses in disposal.

Thus the cartel members must either change premiums and discounts at short notice, or change the allowances given to resident companies to make the crude more attractive to them, or tolerate wide swings in output and market share for any given country. All of these expedients are practical and have been observed in practice, but all are obviously less desirable than the solution for which they are now groping: to fix a scale of differentials which will hold for an appreciable period of time, so that each cartel member may at all times know what every other cartel member is charging. It is well known that the OPEC meetings have paid much attention to this topic and that serious attempts are being made to design and implement such a scheme.

For our research, these considerations indicate the following: First, the overall two-part simulation framework is an essential input to the study of this process, for the level of net demand on cartel sources, and the resulting excess capacity among cartel members, are the dominant factors in any consideration of the details of market behavior. Second, the analysis must include estimates of the market value of each of these differentials--both for purposes of calculating long-run prices in the simulation framework (as shown in Figure 1) and for studying the effects of likely shorter-term disturbances. The work on transportation and refining cost elements is set

forth in Section 4.2. For the refining process, our initial approach will be to set forth a set of imaginary large refineries in the principal importing and exporting centers, and to match-up product price differentials on the one side with the chief elements of the appropriate crudes on the other.

Third, there is need for a continuing process of monitoring and evaluating developments in the market such as

- (1) The company commitments to operations in any given country, and the payment for the services it renders, as well as the discretion of the government in changing that payment.
- (2) The practices of the companies in procuring crude oils.
- (3) The amounts of integrated crude and open market crude in each principal exporting area, and the direct sales made by each important cartel government, and to which non-resident company.
- (4) The progress of the cartel in setting differentials.

For the cartel, these various efforts and policies represent an attempt to avoid the divisive and perhaps impossible task of formal market sharing and output limitation of a more conventional type. The more successful is the control of price differentials, the less attention need be paid to prorationing.

It is through the analysis of these detailed aspects of the market's functioning--backed up by empirical studies and simulation analysis of the gross movements in the market--that we hope to contribute to better forecasts of likely future developments in world oil, and to improved evaluations of U.S. policy choices that depend on the price of international petroleum.

## 2. DEMAND ANALYSIS

In designing the demand analysis, a division has been made between the 15 countries which are the largest consumers of oil, and the rest of the non-Communist world. For the large consumers it was decided that many of the most important questions concerning the demand for oil could be answered only in a framework that allowed for separate studies of energy demand by different economic sectors. So, as shown in Figure 1, where conditions warrant and data permit, the demand sub-module for a particular country will be disaggregated into consumption, industrial, transportation, commercial, and energy transformation demands. (The energy transformation sector includes power plants, refineries, coal mines, etc.)

The residential and industrial sectors will be modeled in considerable detail, at least for the largest oil using countries. The transportation, commercial, and energy sectors will be modeled at a less detailed level at the outset, and therefore the data requirements are less stringent. The exception will be certain countries where the oil vs. nuclear choice in electric generation is of particular importance; to the extent that data and project resources permit, special analysis may be devoted to fuel choice in electric power generation, as shown by the dotted box in Figure 2.

The Communist countries and others which are not substantial importers of oil will be joined into a few regional groupings, and the demand in these regions will be analyzed on the basis of national or regional aggregates with no sectoral breakdown.

### 2.1 Data Development

Our initial data collection goal was to gather the necessary data for the 15 largest oil consuming countries for the years 1955-74. The search to

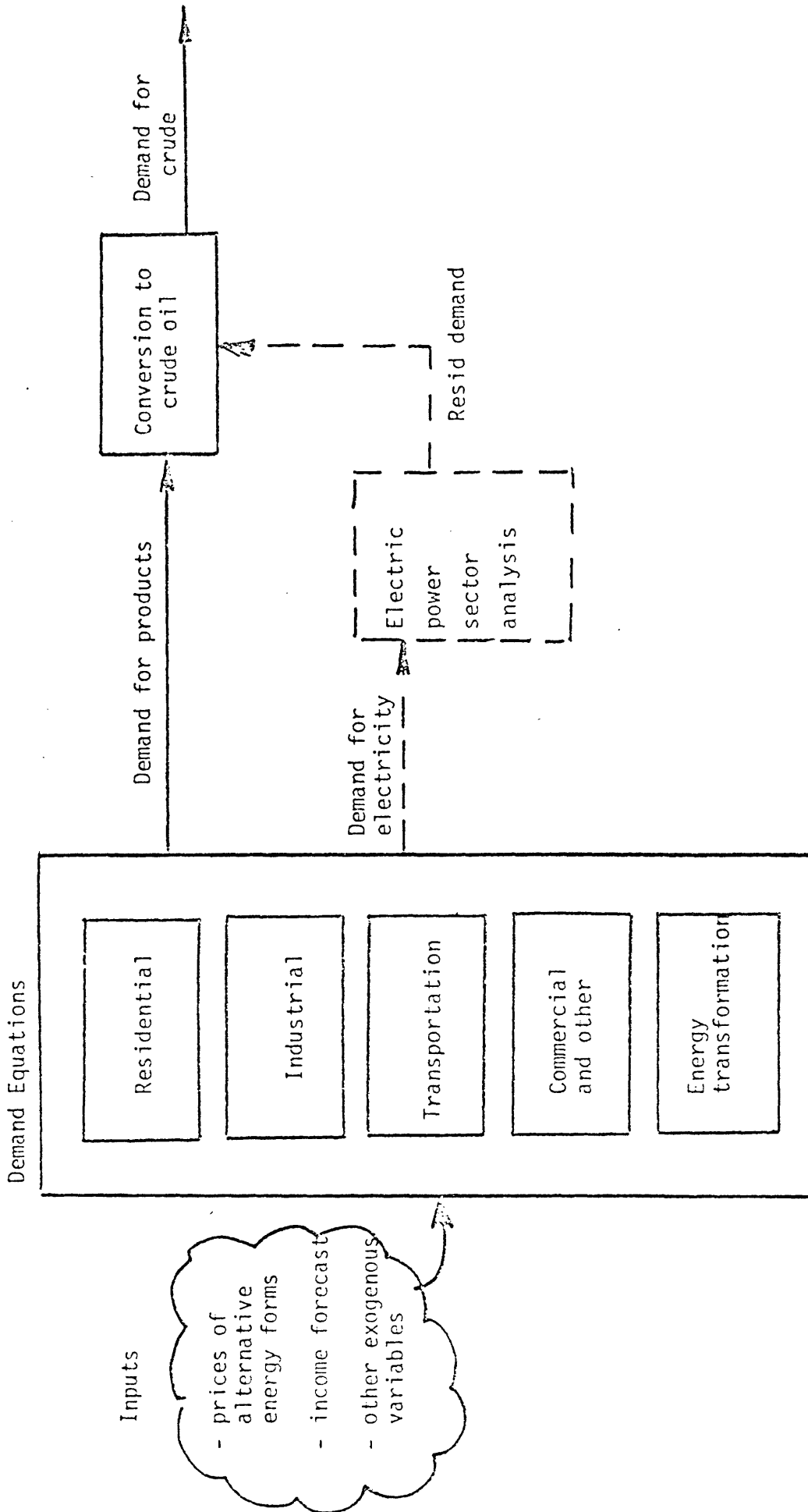


Figure 2. Demand Module for an Individual Country

- Notes: (a) Individual demand equations may be estimated from pooled cross-section data.  
 (b) The electric power sector will be modeled separately only in that limited number of cases where the data permit.

determine what was "out there" began in March, 1975, and the actual collection began in June. We quickly became aware that we were breaking new ground, so to speak, in that much of the information we needed had not been gathered by the agencies to which one traditionally turns for energy data--i.e., the U.N., OECD, or other oil modeling groups.

The available data were particularly weak in the residential sector. For example, we need the retail prices of petroleum products that consumers faced in each of these countries, as well as the retail prices of the direct substitutes for petroleum products--coal, natural and manufactured gas, and electricity. Quantities of each of these energy sources consumed by the residential sector are also necessary. We found that the data available from the U.N. and OECD for these areas were very limited. For example, the OECD lumps agriculture, handicrafts, and residential consumption together. To fill this data gap we have turned to various national publications, such as annual statistical yearbooks. From such publications we have been able to obtain nearly all the necessary data for the residential sector. However, in some countries the data simply were never collected. In those instances it often is possible to estimate the missing information. For example, for some countries the quantities of petroleum products consumed by households were unavailable, but estimates of the amount of money spent by households on petroleum products were available from government yearbooks. Given an average price for petroleum products, an estimate of the quantities consumed can be made.

Traditional sources have proved to be more useful for the industrial sector. For example, the OECD has collected the quantities of fuel consumed by industry for its member countries. For many of its member countries the U.N. has data on expenditures by the industrial sector for energy, capital, raw materials, and labor. We have obtained computer tapes of these data from



each of these agencies. Again, however, it has proved necessary to go to individual national sources for many of the data on fuel prices for industry, as well as for input prices for energy, capital, raw materials, and labor. As with the residential sector, we found that many of the needed data are simply unavailable for some countries. In some cases it will be possible to estimate the data; in others the model that we use will have to be adjusted to take account of the missing data.

With the data gathering effort for the largest oil consuming countries drawing to a close, it appears that we will be able to use our sectoral approach for 12 of the 15 largest consumers. These 12 will include at least the 6 largest oil consumers. Data unavailability precludes modeling all 15 in this disaggregated fashion.

## 2.2 Plans for Estimation

### 2.2.1 Residential Demand

As anticipated in our proposal, residential demand will be modelled using a two-stage procedure, where we first break down the consumption basket for each country into a set of commodity classes, one of which would be energy. This analysis will be very interesting in itself, and will enable us to examine the residential demand for energy and the way that demand fits into the consumption basket in different countries. The second stage is to break energy demand down into demands for alternative fuels (oil, gas, coal, electricity). The advantage of this approach is that it will enable us to analyze the impact of a price change (or change in any other exogenous variable) on the demand for oil in terms of the effect on total energy usage and the effect on fuel choice. This is important with respect to the design of policies for energy conservation.

The expenditure breakdown study will be done using alternative model specifications, both consistent (in terms of additivity) and inconsistent. We will begin work this month in repeating Houthakker's 1965 study [4] using more recent data and our own commodity breakdown. In attempting to confirm his results, we will have the opportunity to explore some basic issues in the pooling of heterogenous data. Next, we will estimate a set of static consumption breakdowns that are consistent: the linear expenditure system, perhaps an additive quadratic model, and certainly a translog system (extending Jorgenson's work [5] to international data). The idea is to push these systems to handle the kind of pooled data that we will be working with. In all cases "within country" and "between country" regressions will be performed to isolate short-term and long-term effects wherever possible. Our objective here will be to answer a variety of questions, including the following:

1. Is it meaningful to pool the data from countries that are structurally quite different? Perhaps it is better to run separate time-series regressions for each country (albeit with only a limited amount of data) than to pool the data and introduce a possible specification error. On the other hand, structural differences across countries might be taken care of through the use of regional dummy variables or regional structural variables.
2. What are the differences between short-run and long-run elasticities (not worrying, for now, about the dynamics of going from the short-run to the long-run)? Are those differences--as estimated for different consumption categories--consistent with the simple theory? Can these differences lead us to an a priori specification of the dynamic structure?
3. Are there some fundamental data problems, including inconsistencies across countries? Hopefully we will learn a good deal about our data from these initial static estimations. Is there much gain in efficiency from the use of more sophisticated estimation methods? The static models would give us an opportunity to experiment with econometric methods in a "controlled" setting where results are relatively easy to interpret and understand.

Our next step will be to specify and estimate dynamic versions of one or more of the static models mentioned above. Dynamic adaptations of the linear expenditure system are straightforward, but designing a dynamic version of the translog function will be more difficult. As noted in Section 1, a basic approach throughout this research is to start with simple formulations and replace them with improved versions as the work proceeds and as time and computer resources permit.

As a result of these estimations, a model (or set of models) will be available to explain total energy demand in the residential sector for many of the major energy consuming countries. Energy demand can then be broken down by fuel type using a second "consistency" model. Logit and translog specifications are obvious choices, and both will be pursued. We will begin with static specifications for these fuel choice models that will allow us to explore the same problems of pooling, long-run versus short-run effects, etc. We will then specify and estimate dynamic versions.

It is important to reiterate that this "sophisticated" approach to demand modeling will be used only for a subset of oil importing countries, since for some countries the detailed data necessary simply are not available; for other countries the data are available, but the countries are small, and the effort and expense of collecting and analyzing the data is not worth the return. Thus, the demand for oil in some countries will be modeled using simple constant elasticity equations, with dynamic adjustments built in.<sup>1</sup> It is expected that this simpler approach will have to be applied to countries that constitute less than 30% of total non-Communist oil demand.

---

<sup>1</sup>In the early stages of the estimation, this approach will have to be followed even for some of the large consumers in order to allow preparation of the overall simulation to proceed even though the demand studies are only partially complete.

### 2.2.2 Industrial Demand

Industrial demand also will be modeled using a two-stage approach. The first stage will consist of a model determining the total demand for energy as a derived factor input in the industrial sector. Our first approach will be to use a translog production function that includes capital, labor, and energy as factor inputs. (It would also be desirable to include materials as an input, but the requisite data are not available.) While we will begin our estimation in this area with a static specification, we will concurrently explore ways of specifying a dynamic version of the translog system.

The second stage of the model would also break total energy demand down into particular fuel choices. Again we plan to test both a logit and a translog specification, static at first, and then dynamic.

### 2.2.3 Transportation Demand

Transportation demand includes gasoline, diesel fuel, jet fuel, etc. used in transport services. This is an area where a considerable change may take place in response to higher prices, particularly in the U.S. Our approach here will be to use simple elasticity demand equations that relate the demand for each fuel to prices, incomes, etc., in a simple dynamic constant elasticity specification.

### 2.2.4 Commercial and Other Demands.

This sector includes stores, office buildings, and other commercial establishments along with schools and other public buildings. In order to apply the more detailed analysis that is being used for the residential and industrial sectors, an additional data preparation effort would be required,

particularly for price information. It appears feasible to obtain these data, but the task is beyond the current resources of the project. Therefore, we intend to use those simple formulations that are allowed by the data easily available.

Naturally, in a subsequent phase of this research, when the more important residential and industrial sectors have been satisfactorily analyzed, we will turn over resources to improving the estimation of these commercial and government activities.

#### 2.2.5 Energy Transformation

The demand for energy by the energy producing sector includes the use of energy (coal, oil, gas, and nuclear) to produce electricity. It would also include the consumption of energy for coal mining, and the consumption of energy in the process of oil refining and natural gas transmission.

Our initial approach to estimation of energy demand by this sector will be to fit standard econometric relations. There is one instance, however, where there is a need for more detailed analysis. This is the fuel choice in electric power production, given the electricity demands estimated separately for the residential, industrial, and commercial sectors. Because nuclear power is not reflected in the historical data, and because the demand for nuclear and coal-fired power, as opposed to oil-fired power, is being significantly influenced by national policies to achieve "independence" of the world oil market, the econometric analysis needs to be supplemented by a special analysis of the process of fuel choice in this sector. As shown by the dotted box in Figure 2, we hope to develop such an analysis,

but it is not yet clear what can be done in this area over the next year of the project given available project resources, and the allocation of those resources over the many tasks at hand. If it does not prove possible to do justice to this problem in the current phase of the work, this will be a high-priority item in a subsequent stage of research on this market.

### 3. SUPPLY STUDIES

In our investigation of supply conditions in the world market, the econometric technique used so extensively in the demand analysis will have to be largely supplanted by geological data, detailed engineering cost estimation, and simulation of government and industry development decisions. There are several reasons why the physical and cost data are so important. To date, most econometric investigations have traced out the effect of price changes, both down and up, on the supply from large productive systems, such as crude oil or natural gas in the United States. Hundreds of fields, each containing a number of reservoirs, have given these systems the stability of large numbers; and the depletion effect, tending to raise costs as less of a reservoir remains, has in large measure been offset by new discoveries and improvements in technology. In studying supply from other areas of the world, the conditions for analysis are less favorable. In many countries the oil fields are both fewer and younger, and even the short histories are poorly documented.

Another factor limiting the use of econometrics in supply studies is that the price series of the past are fragmentary and untrustworthy. The so-called "posted prices" become meaningless around 1960, when they became artifacts used for the calculation of taxes. Data on arms-length sales of crude are insufficient and ridden with too many errors to serve as a basis for econometric investigations. Moreover, the imperfect competition existing even before the dominance by the cartel means that the production response in some areas was governed not only by relative costs and price but by considerations of political stability, desire for diversification to avoid political risk, etc. For these reasons, and orderly summation of the past is of limited help in deciding on future relations between prices and outputs.

### 3.1 Supply Model Design For Price Takers

In this circumstance, the approach we have adopted to the analysis of price-taker suppliers is to develop a simulation of the process of exploration, discovery, and production in various oil producing regions of the world. This is an ambitious undertaking, and we cannot expect to be able to perform this analysis on any but a limited number of the larger basins; the supply from other areas will have to be approximated by far simpler relationships, by judgmental forecasts, or by borrowing from other analyses (as we very likely will do for the continental United States, for example).

The process which needs to be analyzed is summarized in Figure 3. Beginning at the left side of the diagram, exploratory drilling produces a flow of new discoveries in a basin. Depending on costs and the expected oil price, some of these discoveries will be economic to produce; others will be too small to justify the initial cost of development. The resulting collection of pools that are of economic size can be thought of as an inventory of prospects for development--a quantity that may be referred to as "available recoverable reserves." In older areas, this inventory will include some fields that are already being produced, and others which are undergoing development for production in the future. The decisions of firms and governments to develop productive capacity in discovered fields, and the associated rates of depletion of those fields once developed, combine to determine the pattern of supply from each producing area.

The outcome of this process of discovery, development, and production is influenced by a host of factors. Resource constraints (most importantly, the available reserves) are a critical factor; at each stage in the process the costs of development and production are important, along with the expected price at which the oil can be sold. And of course all choices are



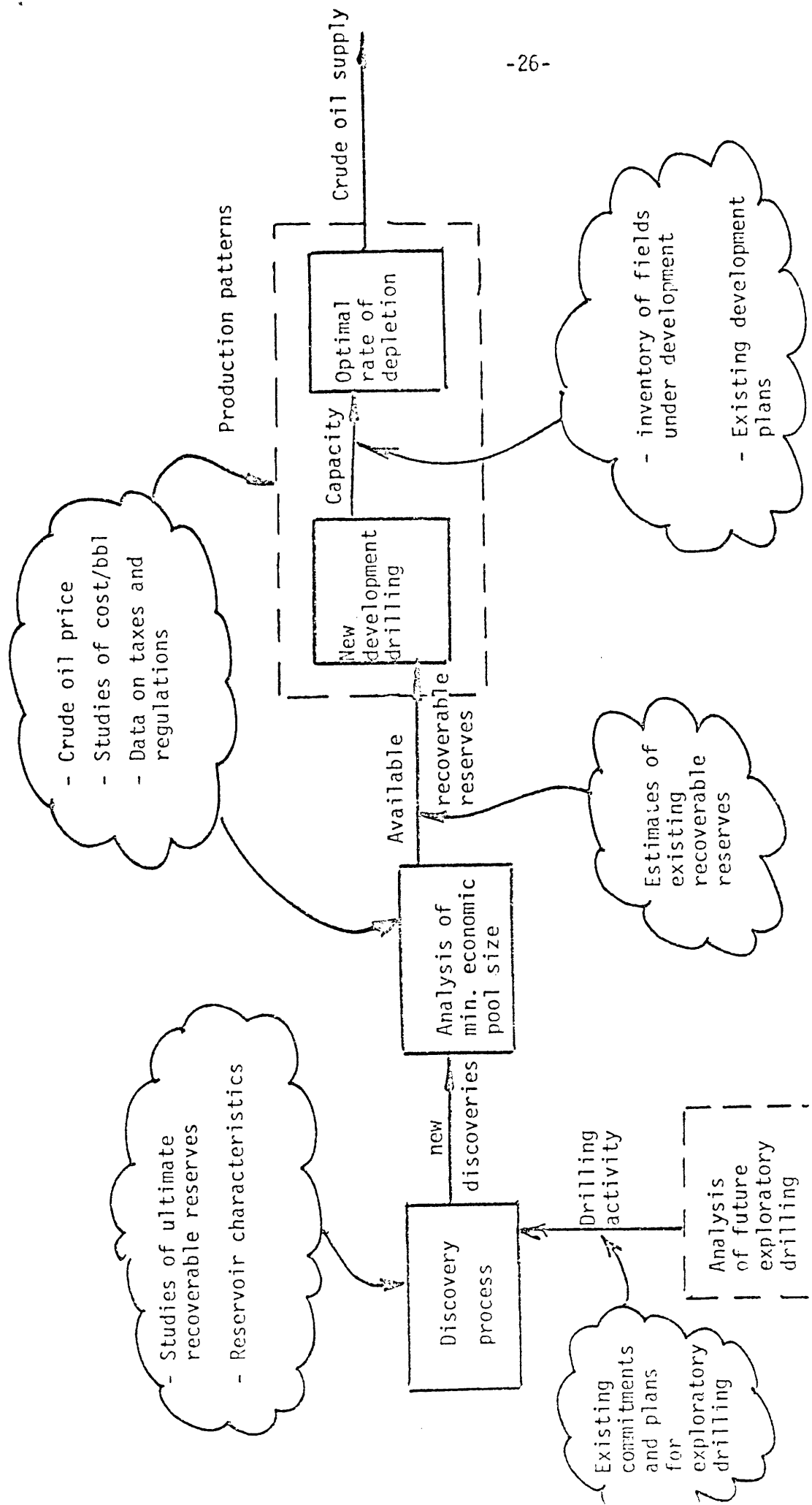


Figure 3. Supply Module for Individual Price-Taker Region or Basin

influenced by the tax policies of the governments concerned. Ultimately, it is our intention to develop a model to simulate this entire process, so that forecasts of likely petroleum supply can be made over periods of time as long as 15 or 20 years. At the outset, however, we will work toward a less ambitious goal, and will construct a supply analysis which can support reasonable forecasts over a five to ten year period. Analysis of the longer run will build on this initial effort.

We will begin our work at the right-hand side of Figure 3 and focus our efforts on constructing a module which can analyze and forecast the supply of petroleum out of known basins over the period when nearly all production will come from reserves that are already fairly well-quantified. These areas fall into three categories:

- (1) fields that are already partially or completely developed
- (2) fields where development drilling is already underway or planned, and
- (3) areas where pools of economic size are known to exist, but development drilling programs have not yet been initiated or planned.

In the first two cases, the estimates of capacity can be based on relatively good data (many of which are in the public domain), and an analysis of the likely rate of depletion can be carried out--taking account of operating costs, current and expected prices, and the relevant regulations and taxes. In the case of the third category of available reserves, it will be necessary to simulate the decisions regarding development drilling and the bringing of new fields into production.

The analysis of rates of depletion of already-developed fields will be the most accurate portion of any forecast of oil supply. The problem is one

of collecting the available data and putting them into a calculation format that will allow proper aggregation and analysis. On the basis of this rather simple analysis, forecasts of up to three years can be made for on-shore fields; for offshore developments these data will give a reasonable forecast for as long as five years because of the very much longer lead times in these areas.

Analysis of the steps followed to bring previously undeveloped reserves into production can extend the forecast horizon up to five years or so onshore, and to as long as seven or eight years offshore. This is possible because new reservoirs which are discovered as a result of exploratory drilling in any year are not likely to enter into production for up to five years onshore or seven or eight years offshore given the normal lead times in the development process.

It is our feeling that, though it be limited in the time horizon it can consider, the analysis conducted at this "downstream" end of the exploration and development process will of itself make a valuable contribution to our understanding of world oil supply. There are several factors that determine oil supply, and in many studies a great deal of attention is given to available reserves, or potentially discoverable reserves as a key determinant. In the long term this may be true, but over the horizon of five to ten years the reserve base, though significant, does not appear to be the dominant factor in oil supply. The key determinants are:

- (1) The time delays in development investment, particularly in high-cost offshore and inaccessible onshore areas,
- (2) The tax rules and exploitation policies of the government's concerned,

(3) The costs of rigs, platforms, and other input factors, and

(4) The current and expected world price of crude oil.

To the extent this is a proper evaluation of the relative importance of these factors, a model which does no more than simulate investment patterns and production profiles from known resources, taking account of available data on programs and plans, can give a reasonable approximation of the expected supply function over this short to medium-term period.<sup>1</sup>

Beyond the five to ten year period covered by this framework based on known reserves, a more complex apparatus is required. The analysis must be extended "upstream" to include the process by which new reserves are added to the available inventory. The determinants of this supply function of reserves include: (1) the expected characteristics of the reservoirs to be discovered, (2) the expected cost of exploring and for developing these reservoirs, (3) the expected fiscal and non-fiscal regimes by which exploratory and production activities are to be regulated, as well as (4) the expected price of oil over the lifetime of production from the reservoirs to be discovered. These four factors determine the economic incentive that corporations will have to look for and produce from oil reservoirs. Very likely each factor will be represented by a separate component in the advanced version of the supply model. By simulating the interaction between these four components, the process by which reservoirs of oil are explored for, found, and transformed into actual supply per period of time from a given geopolitical area can be represented.

---

<sup>1</sup>In this work, we can take advantage of previous work at M.I.T. in this area [7].

There are, however, a number of problems associated with the precise design of each component, as well as the interaction between them. The distribution of various geological parameters is of great significance. Extensive study of the size-frequency distribution of oil reserves has been done by Kaufman [6] and others. We will lean heavily on this work. Aggregating from the size-frequency distribution of pools in a play to the size-frequency distribution of pools in a geopolitical area does, however, raise serious conceptual and empirical problems. Government regulation of the exploratory process introduces irregularities that make it more difficult to predict the most likely sequence of discoveries to be made from a given exploratory effort. Moreover, the cost of looking for, developing, and producing from an individual pool is dependent not only on the geological characteristics of the pool and the relevant government regulations but on the total market for the input factors that are required. The market for some input factors (like rigs) extends beyond the geopolitical area represented to which the module in Figure 3 will be applied, which implies that the problems inherent in a general as opposed to a partial equilibrium analysis will have to be faced.

The future price of oil will be represented in this module by an exogenous price vector as noted in Section 1, where the countries analyzed are those assumed to behave as price takers. The fiscal and non-fiscal regulations to which developers are subject will in general be designed according to the declared political objectives of the relevant government--taking account of existing rules and the relative economic attractiveness of the area. Of course, tax systems are of differing complexity, concession agreements leave room for different interpretations, and other regulations (like production ceilings) may or may not be executed as they are formulated today. The

uncertainty associated with these factors makes it difficult to formulate hypotheses about how expectations are formed in this sector. Such rules will be constructed, however, and by incorporating these components into the simulation framework we will have the flexibility to test alternative formulations of these different influences.

At the outset, under the general approach taken throughout this study, the overall supply module in Figure 1 will necessarily have to be based on some very simple functions for many areas of the world. The actual basin supply module represented in Figure 3 will be constructed using the North Sea as a case example. A second trial area, in order to assure the general applicability of the model design, will be an appropriate onshore region. The total number of basins treated in this manner will depend on the availability of data, our success with the first experiments, and the availability of project resources. At this point it appears that the "downstream" end of the supply module can be constructed for many of the important production areas of the world, based on data that are in the public domain. Naturally, as the analysis proceeds to consider exploratory drilling and its determinants, the data and analysis problems will multiply, and the number of areas subjected to detailed analysis may have to be restricted so far as work in the next 10 to 12 months of the project is concerned.

### 3.2 Data Development and Supporting Analysis

The supply module of Figure 3 will be constructed only for supplier countries that are thought to behave as price takers. This approach is not appropriate for members of the core of the cartel: these countries are engaged in setting the price, not following it, and therefore the production decisions are the result of a wholly different calculus, as discussed below

in Section 4. It is nonetheless important to have information on the reserves and capacity figures in the cartel countries, for these data are important in forming judgments about likely behavior of various members of the cartel. Therefore many of the data that are relevant for construction of the supply module shown in Figure 3 are also desired for the less formal analysis of the circumstances faced within the cartel countries.

The empirical work to support the supply analysis falls into three areas. First is the gathering of data on resource constraints as they are understood today. Ultimate oil and gas resource estimates seem (perhaps for the first time) to have some economic meaning in the sense that overall oil and gas output may reach its peak some time within the next 20 to 30 years, which is at the outer reaches of the analysis being conducted in this project. And, as noted earlier, the amount of available recoverable reserves are estimated with fair accuracy for most countries, but precision decreases rapidly as one examines separate fields and basins. The collection of those data on these various categories of reserves that are in the public domain is being carried out and will continue in the future.

The second area of concern is the current production capacity in each of the major supply areas and the likely evolution of this capacity in the future, given the resource-reserve limits on expansion. These estimates, which are an input to the "downstream" end of the supply module discussed earlier, involve a tabulation and appraisal of current capacity figures and expansion plans announced by companies and governments. It also requires study of the limits on current operating rates: a reserve may be depleted so quickly that the water or gas which serves as the force driving it toward the well breaks through, leaving the oil behind. This need to avoid the risk of losing part of the reserves sets a different kind of

limit on the likely rate of development and exploitation of any given field. The work to date on capacity is summarized below.

A third area of importance to the construction of the supply module and to the understanding of the internal functioning of the cartel is the cost of development under current depletion conditions in key supply areas. Given an oil and gas reservoirs, with known costs and expected prices, there is some rate of depletion which is the most desirable from the standpoint of the company or government managing the exploitation. For example, if one examines development plans in new large reservoirs, the peak rate of depletion is nearly always in the range of 6 to 11 percent of reserves. At higher discount rates, this rate might be speeded up, though once again there may be constraints which make this a very expensive thing to do. Analysis of this question requires data on the capital costs of development in different areas and the various operating costs that are associated with alternative rates of exploitation. The work to date in this area also is described below.

Up to this point nearly all of the effort in data collection and evaluation on the supply side has been directed to countries which are currently members of OPEC, particularly the Persian Gulf nations, or to countries operating in the North Sea. With the recent decision to take the North Sea as our case example in constructing the first stage of a supply module for the simulation analysis, there will be a shift of emphasis to that area, although work on the middle eastern countries will continue. Small amounts of work have been done on the Communist block, primarily Russia and China, and we expect in future months to expand our investigation to include more work on those two countries as well as Mexico, which is currently considered to have a potential for significant exports.



### 3.2.1 Capacity Estimates

Thus far we have made capacity estimates for OPEC members based on estimated total oil well completions for any one year and forecast total completions for the following year. These capacity estimates are dated end-year from 1973 through 1975. For most countries, capacity it is estimated as the sum of the highest level of production attained in that country plus the estimated number of oil well completions times average output per well. For certain countries, such as Saudi Arabia, a local or constrained peak was chosen. We estimate Saudi capacity based on the oil well completions after July, 1973, although it is widely known that daily output has since exceeded that level. The selection of the constrained peak of 1973 for Saudi Arabia, Kuwait, Libya, and Algeria was determined by the political developments in that year.

Capacity estimates may be defined either gross or net. Gross capacity reflects peak production plus estimated capabilities of new wells added. Net capacity reduces gross capacity by the estimated amount of decline in production during the period covered. The change in net capacity can be approximated for any country as

$$\Delta C_{\text{net}} = \Delta C_{\text{gross}} - \frac{(2q \cdot 365)}{R} (q) \quad (3-1)$$

where  $q$  is daily output and  $R$  is the most recently dated reserves estimate.<sup>1</sup>

---

<sup>1</sup>The factor of 2 in the equation is intended to account for differences in the definition of reserves as often reported abroad and the more narrow concept of proved reserves as applied by the A.P.I., which is relevant to the calculation of decline rates.

We have made no judgments as to what fraction of estimated net capacity represents usable capacity. (Others have suggested that for at least one country--Saudi Arabia--installed capacity is generally about 10% more than usable capacity.) Moreover, our net capacity is not precisely identical to the concept of installed capacity, for our method is based on the build-up in well completions, and ignores the necessary complementarity of other field facilities such as gas-oil separator plants, main oil lines, etc. Nonetheless, we feel our capacity estimates for the future are at least as good as others offered, and ours for the past appear in general to be well validated.<sup>1</sup>

Combination of our capacity estimates and monthly production figures reported in the trade press give us current excess capacity in OPEC countries. This we maintain on a monthly basis. An example of the most recent calculation is shown in Table 1.

### 3.2.2 Costs

Capital costs per initial daily barrel of production. To date our investigations have been concentrated in the countries of the Middle East. Our work on Iran and Saudi Arabia can serve as an example of this effort. In the case of Iran we have examined the Capital Look-Ahead plans for the former Iranian Consortium from 1964 through 1973 (onshore fields only, with the exception of Kharg Island). These annual capital forecasts are generally for a period of five years, ending unfortunately with the plan dated September, 1973. These documents give a fairly sound idea of what

---

<sup>1</sup> It should be stressed that any estimate of net capacity or excess capacity depends on an important degree upon the size of the reserves figure used for the purpose of gauging the decline rate. Even a respected source, the International Petroleum Encyclopedia, contains inconsistencies (which have been removed following correspondence) between two of its own tables, and with other sources.

Table 1. Reserves, Production, and Capacity for Key Exporters as of August 1975

	January 1975 Reserves (billion bbl)	Production Thousand bbl/day	Percent of Reserves	Estimated <sup>a</sup> Net Capacity <sup>a</sup> (thousand bbl/day)	Excess Capacity (thousand bbl/day)	Percent Excess Capacity
OPEC	489.1 <sup>b</sup>	29,339 <sup>b</sup>	2.19 <sup>c</sup>	40,420	11,081	27.4
Iran	66.0	5508	3.05	7,072	1,564	22.1
Iraq	35.0	2261	2.36	2,500	239	9.6
Kuwait <sup>d</sup>	81.4	1957	0.88	3,695	1,738	47.0
Saudi Arabia <sup>d</sup>	173.1	8211	1.73	11,822	3,611	30.5
UAE, et al <sup>e</sup>	45.9	2621	2.08	3,223	602	18.6
Algeria	7.7	900	4.27	1,201	301	25.1
Libya	26.6	2092	2.87	2,507	415	16.6
Nigeria	20.9	1700	2.97	2,580	880	34.1
Indonesia	15.0	1385	3.37	1,878	493	26.3
Gabon	1.75	210	4.38	256	46	18.0
Ecuador	2.5	194	2.83	338	144	42.6
Venezuela	15.0	2300	5.60	3,348	1,048	31.3

Notes:

- After allowance for decline.
- Sum of countries listed below. All production figures from Petroleum Intelligence Weekly 9/22/75 and 9/29/75.
- Percentages calculated using August, 1975, daily output.
- Including Neutral Zone.
- UAE, et. al includes Abu Dhabi, Dubai, Sharjah, Qatar, and Oman.

has been the historical pattern of the capital cost per developed barrel, as well as the anticipated cost, in a land area remarkable for its difficult drilling conditions.

Generally speaking, capital costs of development should include all costs of developing production from the wellhead to the point of export. For the former Iranian Consortium, and presumably for other operators elsewhere in the world, there are three major definitions of capital costs of development: (1) costs of field facilities, meaning production units, boosters and pumpsets, main-oil-lines and loops; (2) costs of (1) plus flowline and well costs; and (3) costs of both (1) and (2) plus (Kharg) terminal costs. From Iranian data we are attempting to extrapolate capital costs per initial daily barrel for land areas elsewhere in the Middle East. The 1973 Iranian forecast of capital costs, made before the full impact of the current inflation was known, placed per barrel development costs for 1974 and 1975 at \$220 and \$132 respectively (in 1973 prices).<sup>1</sup> On the other hand, we find evidence of steeply rising marginal costs in Iranian onshore fields, for any expansion much beyond the current estimated capacity of about 6.5 to 6.6 million barrels per day.

It should be noted that the cost of output and capacity in Iran, or in any other producing area, is not only determined by the costs of net new increments installed, but by the costs of continuous maintenance of existing well capacity. We had long thought the decline rates to be below 5% per year in the Middle East, yet Iranian documents suggest that output from

---

<sup>1</sup>For those two years, the capital costs per barrel include anticipated expenditures for wellhead separators and pumps, production units, and pumps, boosters and compressors, and main oil lines. While fluid injection plans to maintain pressure were carried as addenda items, such amounts are not included in the above coefficients.

existing wells was expected to decline by more than 50 percent during the 1974 through 1978 period in the absence of maintenance, fluid injection, and the drilling of new facilities. Annual decline rates were estimated at 17.8 percent if no remedial work occurred; these were reduced to 9.4 percent if stimulation, workovers, and desalination programs were carried out; they were further reduced to just under 8 percent if wellhead separators, loops, and boosters were installed in addition to the stimulation and other programs.

Turning to Saudi Arabia, we can see some of the difficulties presented by incomplete or conflicting data sources. One would expect to find capital costs for development of onshore prospects less costly than in Iran, for the drilling conditions are less formidable in Saudi fields. Unfortunately, we have not been permitted access to Aramco documents similar to those of the former Iranian Consortium; thus all conclusions are based on publicly available data presented before the Senate Foreign Relations Committee, Subcommittee on Multinational Corporations, and calculations made therefrom. These data have been extremely difficult to use, for we have no precise idea of the timing of capital programs as those are turned into streams of expenditures, nor do we know the length of time between the initiation of an expenditure program for expansion and the resultant increase in effective capacity. Several attempts to interpret the Senate Committee presentations to date suggest that on average capital coefficients in Saudi Arabia range from \$100 to \$260 per barrel in 1973 dollars. These figures are not at all in agreement with the press reports of \$200 onshore and \$400 offshore in "the Middle East," nor are they in agreement with the "unit cost" (i.e., unit investment) figures reported by Aramco for the onshore fields of Shaybah (\$1300 in 1975 prices), Haradh (\$510 in 1973 prices), and Khurais-Mazalij (\$810 in 1973 prices).

If we subtract estimated operating costs of \$214.4 million from Aramco's total 1973 expenditures of \$374.8 million, then Aramco's capital expenditures in that year are estimated at \$160.4 million.<sup>1</sup> (The rig-time method of estimating capital expenditures gives \$166.6 million for Aramco in 1973, which confirms the magnitude of the first estimate.) From Aramco's Annual Report, we know the company installed over 3 million barrels per day of capacity in 1973, for a capital coefficient per initial daily barrel of approximately \$55. Even if we were to assume that all of the \$374.8 million was capital expenditure, the capital coefficient would still be no more than \$125 per barrel, well below the other estimates cited above. But it may not be correct to associate capital expenditures in any one year with new capacity going onstream in that same year. Large capital expenditures might be made in a year in which very little new capacity was fully introduced, thus generating a very high capital coefficient. Or, as in the 1973 case, the coefficient may be remarkably low, perhaps because the whole 3 million barrel per day capacity increment was waiting on only the last in a series of expenditures on complementary facilities. What we do not know, and need to pursue, are the time lags involved as well as the discrete nature of the expansion process.

The results of a thorough perusal of the literature dealing with announced capacity expansion programs permit us to array the prospects from lowest to highest cost. These prospects are by field, both offshore and onshore, in Iraq, Egypt, Neutral Zone, Iran, Indonesia, Abu Dhabi, Gabon, People's Republic of the Congo, and India.<sup>2</sup> The Iraqi North Rumaila

---

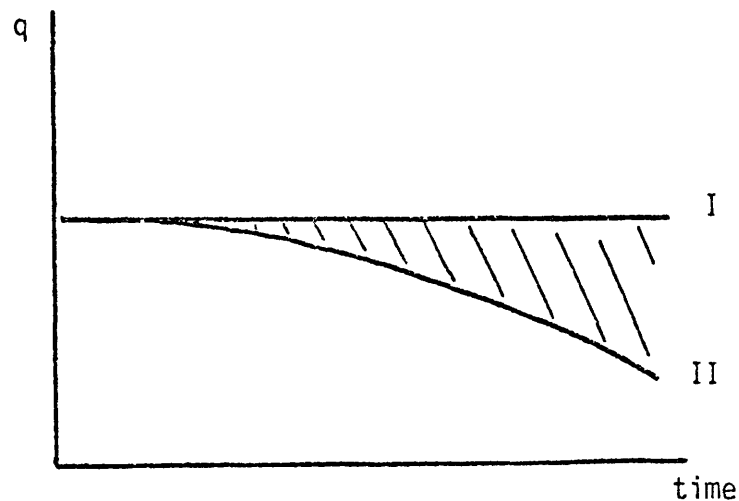
<sup>1</sup>Total expenditures are calculated by multiplying 1973 output by Petroleum Intelligence Weekly's outlay per barrel of \$0.14; operating costs are figured at \$0.08 per barrel.

<sup>2</sup>Saudi Arabia is included, but costs are Aramco's "unit costs" rather than estimated capital coefficients of development.

field is lowest at about \$200 (1973 dollars), while India's Bombay High offshore field is estimated at \$3125 in 1975 dollars.

Yet the costs of developing additional capacity from all of these fields (with the exception of Bombay high) are far less than those for the North Sea. Here we place the range of coefficients, for the British sector only, at from \$2,000 to \$10,000 per initial daily barrel in current dollars. These costs are based on company estimates made public, and are constantly subject to revision.

Discounted capital costs per barrel. Perhaps the more appropriate assessment of costs among fields and between areas is one based on the cost of production over the life of the field, rather than a strict ranking of cost coefficients as of the current point in time. Announcements of secondary recovery programs with the anticipated costs and levels of maintained production are particularly helpful in this regard. Not only are substantial expenditures being made in Iran on this account, but as well in Abu Dhabi, Dubai, and Saudi Arabia (the Ghawar field in particular). Most fields in the British North Sea are expected to commence production with pressure maintenance. If we assume a stabilized production level for a twenty-year period, such that there is no decline during that time, take a discount rate of 20 percent per year as an example, and a decline rate in the absence of such programs based on the recent average production-to-reserves ratio of the particular field or area, we may calculate the discounted capital cost per barrel of the secondary recovery program. In effect, we are trying to establish the cost of the production represented by the shaded area below, where curve I represents the stabilized production level and curve II represents the production path over time without expenditures for pressure and capacity maintenance.



More specifically, we may state those future barrels to be recovered in present barrel equivalents, where the PBE, in billions of barrels, is:

$$PBE = q \cdot 365 \left[ \left( \frac{1 - e^{-rt}}{r} \right) - \left( \frac{1 - e^{-(a+r)t}}{a+r} \right) \right] \quad (3-2)$$

The decline rate,  $a$ , is to be offset by the expenditures for capacity maintenance; thus we calculate discounted per-barrel costs as expenditures divided by the PBE. For Iran, we place these costs at about \$0.17 per barrel, in offshore Abu Dhabi at from \$0.91 to \$0.99, and at Ghawar in Saudi Arabia at \$0.48.<sup>1</sup> In contrast, we estimate discounted capital costs per barrel in the U.K. North Sea fields to be far higher--from \$2.64 to \$2.98 in the Forties field, \$1.09 to \$3.59 in Ninian (this field's potential has

---

<sup>1</sup>It is surprising to find the Ghawar cost to be higher than that estimated for onshore Iranian fields. We suspect this may be an artifact of the particular ranges over which these figures are estimated. The Ghawar costs are for an expansion from the current 5 million barrels per day to as high as 8 million, whereas the Iranian costs are for a range close to the current output of 5 to 6 million barrels per day. There are indications that Iranian costs rise many many fold at an output not much above the current level.



recently been revised downward substantially), and at just under \$5.00 per barrel in Brent. In all these calculations the choices of the discount factor and the anticipated decline rate for not-yet producing fields are critical.

Current variable costs of production. We should for all producing areas like to have an accurate reading of current production costs per barrel. Our efforts have been slowed here because of the peculiarity of reporting in the trade press, where "costs" on a per-barrel basis appear to be simply total expenditures, both capital and operating, divided by current production. This method gives a cost of 25¢ per barrel in Saudi Arabia, yet only 19¢ in Iran. Such a ratio seems to contradict all that is known about these two areas.

Our own view is that current variable producing costs in Saudi Arabia are about 8¢ per barrel, about the same in Kuwait, and about 12¢ per barrel in Iran. Clearly, we have not been able to reconcile the wide range of production costs in Saudi Arabia. At the other end of the scale, current estimates of operating costs of some U.K. North Sea fields are expected to be no less than \$2 to \$3 per barrel. But our estimates are very weak for all areas.

Statistical Studies of Costs. While we have many estimates of capital coefficients of varying quality for a number of areas and fields, there are other producing areas for which we have none. In order to fill this gap, we have tried to estimate capital expenditures econometrically in various parts of the world. The minimum objective of this approach was to validate the reliability of allocating rigtime expenditures within each region in the Chase Manhattan capital expenditures series [1]. The independent variables used were onshore and offshore rigtime, plus capacity added per well to capture differential surface capital expenditures.

Worldwide, most of the variation in expenditures was explained. In some of the half-dozen principal regions of the world, the variation in expenditures was satisfactorily explained by the rigtime method; in others, it was not. But the coefficients serving to estimate expenditures directly from rigtime data without the need to allocate regional expenditures figures were not sufficiently stable and their standard errors were unacceptably large. The possible causes for the mixed results include (a) only 13 data points for each region, (b) measurements errors in the rigtime data, (c) year-to-year lumpiness in investment, and (d) multicollinearity between onshore and offshore rigtimes..

#### 4. STUDY OF MARKET-CLEARING PROCESSES

If this were a competitive market, then it would be a straightforward matter to take the results of the demand studies and the analysis of price-taker supply, add some information on transport and refining cost, and construct a model of market behavior with these components alone. In a competitive world, all suppliers are price takers, and a supply-demand equilibrium can be calculated using well-established principles. The market will equilibrate in such a way as to maximize the sum of consumers' and producers' surplus--the ultimate result depending on the demand elasticities of the importers, the supply functions of the exporters and the costs of transport and refining. The "market clearing process"--that is, the process by which it is determined who sells what to whom, and at what price--is precisely the higgling and bargaining in the market: the "invisible hand" of the classical economists.

The current world oil market is far different. First, the overall price level in the world oil market is now set by the coordinated actions of members of the OPEC cartel. This price level is stated in terms of a "marker crude," usually the F.O.B. price for Saudi Arabian light crude oil. Under our "two-model" approach outlined in Section 1, the analysis of likely cartel behavior in setting this price level is carried out in models separate from the general simulation framework. Our progress in developing and testing these cartel behavior models is covered in Section 4.1 below.

Of course, the focus of this study is not only on the price strategy of the cartel, but on the ability of the cartel to sustain any given strategy under the latent competitive pressures to which any price-fixing arrangement

is subject. (A major purpose of the simulation framework, as pointed out in Section 1, is to provide a "numerical laboratory" for testing the consistency of various hypotheses about market structure and cartel price policy.) The capacity of a cartel to sustain a price far above the competitive level depends on its ability to control supply (and the price shaving that may be needed to sell additional supplies) from within its own ranks. And this problem of internal discipline is intimately tied up with the issue of transport costs, quality differentials and the associated price structure in the market, given any price level.

This is true because the cartel does not have any formal mechanism for allocating production among its members. The production in any area is a function of a number of elements including (1) the production policy of the government, (2) the crude oil needs of the integrated international oil companies, considering the demand in the particular countries they serve, and (3) the relative price of oil at one source as opposed to another. As transport rates and quality premia fluctuate, producer countries try, each on his own, to adjust their prices so as to avoid large swings in output from one country to another,<sup>1</sup> and yet at the same time avoid the progressive price shaving that can occur under a process of constant adjustment of the structure of prices.

Thus the study of the transport market, and of quality differentials and associated refinery costs, play two roles in the overall analysis. They are required to establish the linkages in the overall simulation model, as shown in Figure 1. They also are important to the analysis of the way short-run swings in transport costs and quality premia can put pressure on the cartel

---

<sup>1</sup>The recent OPEC conference shows how sensitive the members were to these fluctuations.

price itself. Progress in analysis of this part of the system is described in Section 4.2 below.

Finally, international transfers of oil have to be paid for, and this raises the issues of the financial aspects of this market. Financial factors come into play in two ways. First, the character of the financial instruments available have an influence on the value of oil production to an exporter with revenues in excess of current import needs, and this may have some influence on the desired rate of output. And second, these financial flows must be "cleared" through international markets for financial assets and goods, and the problems of this adjustment process are part of the evaluation of the implications of any given market scenario, as shown in Figure 1. Our activity in this area is covered in Figure 4.3.

#### 4.1 Behavioral Models of OPEC Pricing

In a cartel-dominated market, one of the more difficult tasks for the cartel members is to come to agreement on the price level for the commodity they control. Of course, if the cartel has sufficient internal discipline, and efficient ways to redistribute funds among the members, it would clearly be to the group's advantage to behave like a monopolist. That is, they should coordinate their production plans as if they were a multi-plant firm, charge the price that maximized the present value of group revenue over time, and distribute the proceeds among the members in a way that kept everybody happy. Indeed, approximations of such a monopoly solution give considerable insight into likely cartel behavior, and we have conducted several experiments with this type of model, as reported below.

Unfortunately for the analyst, however, this is not the whole story.

The cartel members are not a homogeneous group, and their interests (political as well as economic) do not necessarily coincide. Neither do they have a mechanism for joint production planning or for financial compensation of members who may be disadvantaged by one or another group pricing policy. In fact, at times it may be difficult for the cartel leaders to determine who is in the cartel and who is out. As noted earlier, several members of OPEC appear to behave as "price takers," and thus are outside the cartel so far as group discipline is concerned. Others in the core of the cartel itself still may have conflicting interests, and may form into shifting coalitions within the larger group in an attempt to achieve their individual objectives.

The complexity of the process that ultimately determines price is evident from a casual reading of the news reports of OPEC meetings. It is not surprising that the theoretical work on oligopoly behavior has failed to produce the straightforward analytical results that are possible with competitive markets or pure monopoly.<sup>1</sup>

In this circumstance, we have pursued several parallel approaches in an attempt to develop methods of analysis of cartel behavior that shed light on this particular case. Two efforts, one by Pindyck and another by Weitzman and Cemer, involve formal dynamic optimizing models either of a monopoly

---

<sup>1</sup>A review of 51 cartel agreements in 18 international commodity industries [2] does reveal a history that is consistent with available theoretical literature. The more efficient cartels occurred in circumstances where concentration of production was high, the cartel's market share was high, where the membership had cost advantages over outsiders, and where demands were inelastic. However, even in these favorable circumstances the average life was only four to six years, though when a cartel collapsed there usually was an effort (often successful) to reestablish it. Moreover, the history indicates that cartels fare worse when governments are involved.

case, or simple two-coalition situations. Another by Eckbo [3] looks at desired price patterns for various configurations of the cartel, considering the allocation problems within the group. The Eckbo model was intended both as an exploration of ways to model cartel price policy and as a first-stage experiment in the process of preparing the simulation framework discussed in Section 1. The Eckbo model is based on an extension of the theory of static monopoly behavior, and is designed to allow calculation of the implications of various production quota systems as well as pricing strategies within the cartel.

#### 4.1.1 Dynamic Optimizing Models

In the search for analytical models that can capture the dynamics of the cartel's pricing problem, two approaches are being explored.<sup>1</sup> The flavor of the work can be seen in an optimal control model that shows great promise for yielding insight in this area. The first version of this analysis is a monopoly model and assumes that the cartel sets the price of crude oil over time (providing only as much as can be sold at that price) so as to maximize the sum of discounted profits. (Currently this model does not take account of how cartel members will reconcile differences in objectives, or how prices can be determined to maximize cartel stability given these differences.)<sup>2</sup>

---

<sup>1</sup>The example shown here uses the Pindyck model. Weitzman and Cremer have tried a full dynamic optimizing approach that has many of the characteristics of the optimal control approach described in the text, but uses a different formulation of the cost of supply and a different view of importer price expectations. The Weitzman-Cremer model will be reported in a forthcoming discussion paper.

<sup>2</sup>The optimal pricing patterns for the simple monopoly case may also provide some information about the ability of the cartel to hold together in the long run. If the optimal pattern calls for fluctuations in price with periods in which output (and revenues) are very low, some cartel members might find this hard to accept. On the other hand, a pricing (output) policy that

What makes this problem interesting is that supply from the price-taker suppliers is not inelastic in the long run, and has a dynamic dependence on prices (through the process of exploration and discovery of reserves, as well as the development of alternative energy sources). If the cartel sets too high a price, competitive supply will increase as a result of offshore drilling, etc. Thus the cartel must discourage excessive "entry," and is faced with a dynamic limit pricing problem, in which price cannot be set too high, or cannot be maintained at a high level for too long. In setting price, the cartel must consider the dynamics of exploration, discovery, and production of oil (and oil substitutes) by the price-taker fringe.

Our initial formulation of the problem is quite simple. The model describes the total demand for oil as a function of current and past prices, and supply of oil from price-taker suppliers as another function of current and past prices; the demand for cartel oil is simply the difference between total demand and price-taker supply. We assume that the OPEC countries have, in the aggregate, a fixed reserve base, and that as the reserve base is depleted the marginal cost of production rises, becoming infinite as reserves approach zero. We can thus solve a classical optimal control problem, maximizing the sum of discounted profits subject to the constraints of the behavioral model.

The basic model is specified to account for differences between short-run and long-run price elasticities both in demand and in competitive supply. Parameters in the model were chosen to be "reasonable," i.e., to be roughly

---

satisfies the needs of all of the cartel members may be very far from the optimal monopoly price. Similarly, unless output rationalization (or side payments) can be effected easily, an optimal monopoly behavior may result in unacceptably low revenues to some members, thus encouraging cheating.



consistent with elasticity estimates in the OECD study [8], and with crude elasticity estimates that we obtained from aggregate time-series data. The equations of one simple version of the model are as follows:

$$TD_t = 3.5 - .15P_{t-1} + .87TD_{t-1} \quad (1)$$

$$D_t = TD_t - S_t \quad (2)$$

$$S_t = 1.5 + 0.1P_t + .75S_{t-1} \quad (3)$$

$$R_t = R_{t-1} - D_t \quad (4)$$

$$\text{Max } W = \sum_{t=1}^N \frac{1}{(1+\delta)^t} [P_t - m_o/R_t] D_t \quad (5)$$

where  $TD_t$  = total demand for oil (billions of barrels per year)  
 $D_t$  = demand for cartel oil (billions of barrels per year)  
 $S_t$  = supply of competitive fringe (billions of barrels per year)  
 $m_o/R_t$  = average production cost for cartel (\$/barrel)  
 $R_t$  = reserves of cartel (billions of barrels)

The demand equation (1) is based on a total demand of 18 billion barrels per year at an equilibrium price of \$6 per barrel, and gives an average short-run elasticity of .05 and a long-run elasticity of .4, with a Koyck adjustment. This is actually reasonably elastic; the elasticities are 0.1 and 0.8 at a price of \$12 and demand of 18 billion barrels.<sup>1</sup>

---

<sup>1</sup>Note that there is no autonomous growth in demand, e.g., in response to GNP growth or population growth. We are interested here only in price effects. This means, however, that our results for the optimal price will be on the low side, since it is reasonable to expect at least 3% annual growth in demand if there were no change in price.

The price-taker supply equation (3) has, at a \$6 price, an average short-run elasticity of .1 and a long-run elasticity of .4, again with a Koyck adjustment. At an equilibrium price of \$6, competitive supply is about 6.5 billion barrels per year.

Note that the average cost of production for the cartel increases hyperbolically as  $R_t$  goes to zero. In performing the optimization, we take the initial (1975) reserve level to be 500 billion barrels. In addition, we set  $m_0$  at 250, so that initial average cost is 50¢ per barrel.

In performing the optimizations, we initialized the problem by setting the OPEC price at \$11.50 in 1975 (close to its actual price), and calculate an optimal set of prices over the next forty years, in constant 1975 prices.

We have experimented with this model for a number of alternative elasticity assumptions, and Figure 4, which is based on the data specified above, shows a typical result at real discount rates of 5 and 10 percent.

The results call for an increase in price to \$13-14 in 1976, and then a drop to about \$8 in 1980, and a slow rise in price thereafter. The reason for the higher prices in the first few years is that OPEC can take advantage of the difference in short-run and long-run elasticities. It will take 3 or 4 years for demand to drop and price-taker supply to increase in response to a high OPEC price, so that it is optimal for the cartel to set a high price and capture large profits in the first few years.

Note that the higher discount rate (.10 vs. .05) results in a higher price and lower rate of depletion of OPEC reserves. The higher price results in less production but higher cartel profits in the first five years (as well as lower profits in later years) since short-run elasticities are small. Thus reserve depletion is not a significant problem for the cartel operating

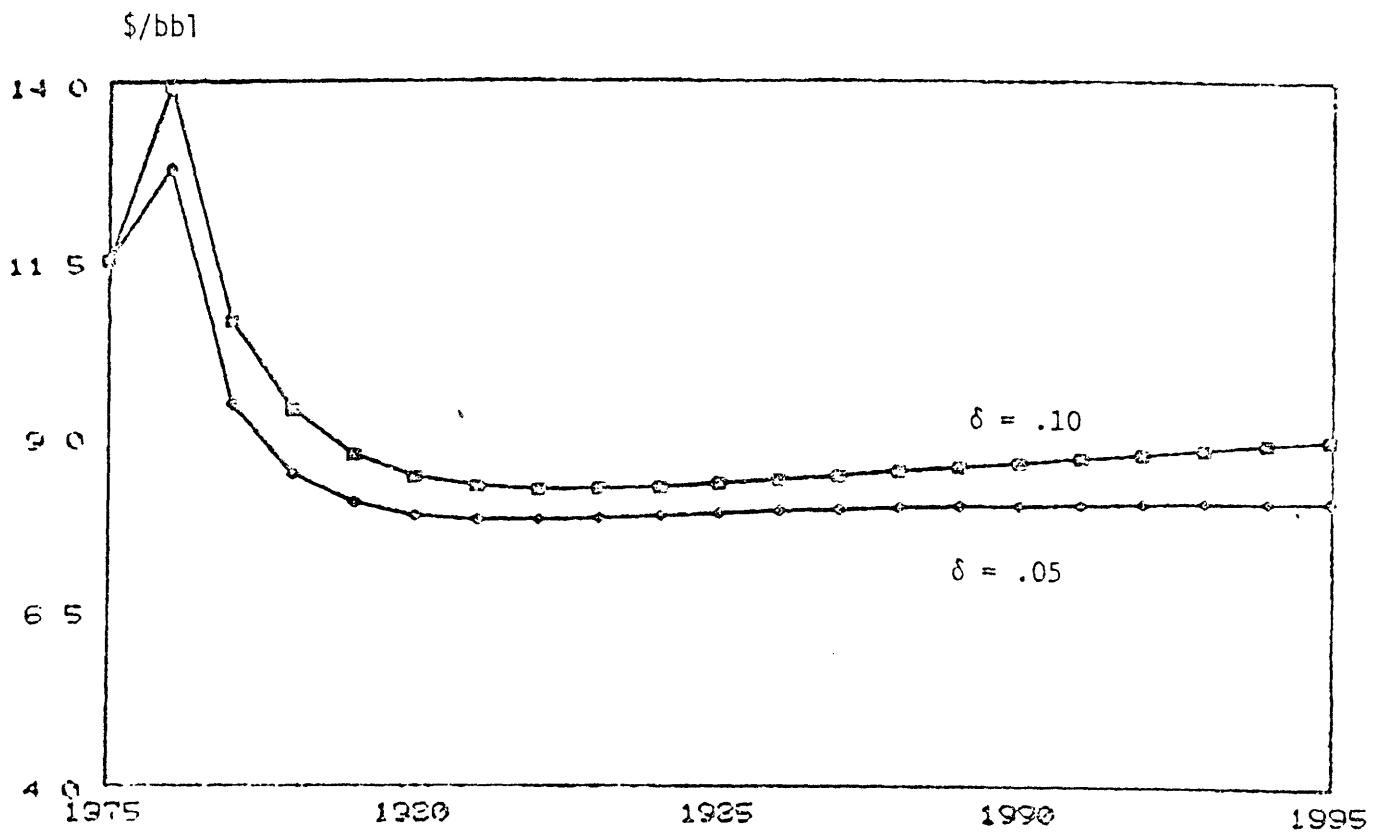


Figure 4. Cartel Pricing Experiment

as a monopolist. In this model, as aggregate reserves drop from 500 billion barrels to 250, production cost doubles (to \$1 per barrel), reducing profits only by 50¢ per barrel. (It will be interesting to examine a model in which production costs rise more rapidly as reserves are depleted.)

Clearly our initial results are limited by the simplicity and inaccuracies of the model. Later we will experiment with larger and hopefully more realistic models that, among other things, take into account the process of exploration, discovery, and potential reserve depletion on the part of the competitive fringe. In addition, work is underway on a version of this model that views OPEC as a two-member cartel rather than as a monopolist.

#### 4.1.2 "Story-telling" Exercises

The framework developed by Eckbo [3] also has been used to develop and test a number of scenarios or "story-telling" exercises about cartel price policy. For example, in one such exercise, OPEC was subdivided into three sub-groups:

- The "hard core" of the cartel, which was assumed to consist of the countries that have the largest recoverable reserves of oil, produce at the lowest rate of depletion, have the highest level of excess capacity, have the highest financial surplus level, and have demonstrated an ability to work together within a colluding agreement. Included in this group were Saudi Arabia, Kuwait, U.A.E. and Qatar, and Libya.
- The "price pushers"--a group that consists of the countries that produce at the highest level of depletion, have the lowest level of excess capacity, and have a strong need for current income. Iran, Venezuela, Ecuador, and Algeria were included in this category.
- The "expansionist fringe," which consists of the countries that produce at an intermediate rate of depletion, expanded production at a rapid rate in 1973/74, have a high need for current income, and do not have their major export terminals in the Persian Gulf. Indonesia, Iraq, Gabon, and Nigeria were placed in this group.

Given this breakdown, a number of simulations can be made, testing various hypotheses about which group dominates in price-setting discussions and how production is allocated among group members. As an example of this type of exercise, Table 2 shows a scenario similar to that prepared by the OECD [8] where the price is assumed to remain at \$9.00 per barrel in 1972 dollars over the period to 1984. Some rough estimates of import requirements (based on a survey of estimates by others) are included in this calculation, and it is assumed that 1974 market shares prevail over the period. A real rate of return of 5 percent is assumed for OPEC investments abroad.

It can be seen from the first set of columns that under these assumptions income from oil exports and the earnings of financial assets abroad will fall short of the import requirements of the "expansionist fringe" by 1978 and of the "price pushers" in 1980. The level of excess capacity in the "expansionist fringe" might be as high as 5.5 million barrels per day in 1978, and one would expect these conditions to place severe strain on cartel discipline.

Based on these calculations, one then is led to experiment with different pricing strategies and quota systems to see which patterns are internally consistent and plausible, and which appear unlikely based on analysis of their implications for participating members of the cartel.

These simulations from models of cartel behavior then provide the pricing assumptions for the larger and more detailed simulation described in Section 1.

TABLE 2. Sample Calculation of the Financial Implications of a \$9.00 per Barrel Price  
and Historical Quotas (billions of 1972 dollars)

	Expansionist Fringe		Price Pushers		Accumulated Assets Abroad		
	Oil Income	Import Needs	Oil Income	Import Needs	Expansionist Fringe	Price Pushers	Cartel Core
1975	18.0	10.0	35.1	13.0	14.3	41.7	75.4
1976	18.1	11.1	34.8	15.0	18.5	60.9	106.5
1977	15.7	14.3	34.5	18.8	19.9	76.6	136.6
1978	15.3	17.3	34.3	22.5	18.0	88.4	166.9
1979	14.6	20.7	33.5	27.0	12.0	94.8	193.9
1980	13.6	24.8	32.4	32.4	1.0	94.7	220.1
1981	13.5	27.3	33.2	35.7	-13.0	92.3	246.7
1982	13.2	30.0	34.0	39.2	-29.7	87.0	273.7
1983	12.1	33.0	33.3	43.2	-50.6	77.2	299.4
1984	12.9	36.3	36.7	47.5	-73.9	66.4	328.0

#### 4.2 Transportation and Refining

These models of the level of OPEC prices must be supplemented with analysis of the role of transportation and refining in determining the overall structure of prices. There are several reasons why the transport market must be considered. First, because of the distances involved and the heavy investment required for tankers, loading, unloading, and storage facilities, and the cost of fuel oil and insurance coverage, the cost of transporting oil is not insignificant relative to the cost of crude oil itself. (In the past, because of the "low" price of oil in percentage terms the transportation cost was more significant than it is now, but in absolute terms it is now larger.) Unless we understand how transportation costs affect oil prices we will not be able to predict the latter.

The markets for transportation capacity are highly competitive, and because of the low elasticity of short-run demand, wide fluctuations in rates are observed. In order to understand oil pricing, we must be able to determine who absorbs what part of these fluctuations and what are the implications of such on the behavior of the producing countries. Oil is mostly sold on a delivered basis, and therefore the fluctuations in transport costs create pressures on the price structure and price levels for oil, as noted in Section 1. Whenever the transportation rates are low, distant producing countries have, other things equal, a comparative advantage over countries which are closer to the consuming centers, and vice versa. This requires "instantaneous" adjustments in the F.O.B. prices if delivered prices are to remain constant at the market place. The fluctuations in tanker rates, therefore, are not only administratively bothersome, but they also create fluctuating "net backs" to the various producers. Where choice

exists, these fluctuations will encourage shifts in the liftings from one country to another, and thus will strain alliances. This is an important phenomenon which needs to be fully analyzed.

Of course the greater the margin between out-of-pocket costs and delivered prices, the greater (again other things remaining constant) the ability of sellers to absorb fluctuations in the cost of transportation and thus to withstand pressures on the cartel price. The ever-changing nature of arrangements between the international oil companies and the OPEC countries creates new possibilities in this realm, however. On the one hand the trend, in ownership of production facilities (i.e., the move toward 100% participation) results in smaller margins for the transporter/refiner, and a reduction in the flexibility of international oil companies to absorb significant changes in the level and structure of rates. On the other hand, there is the ambition of producing countries to become major forces in the area of transportation and even refining. If this means the elimination of the international oil companies as intermediaries, then pressures for the exporting countries to absorb freight differentials may increase, which in turn will put pressure on "net backs." The significance of these pressures depends on the relationships among the international oil companies and the producing countries, and on the degree to which the latter enter into the area of shipping and refining. It is important, therefore, to monitor this portion of the market very closely.

Research to date has focused on the determinants of spot transport rates, so that projections can be made on the current cost of transportation at various points in time. There are at least four dimensions of the short-run cost of transportation which are relevant for our research.



- Short-Run Cost Structure. We need to know the operating costs for tankers of different sizes. This will enable us to develop scale curves for the industry and a static short-run supply schedule of transportation capacity. Based upon a selection of the "relevant" vessels for the various runs (routes), we will develop a matrix of costs so that we can determine the landed price of oil under various conditions.
- Level of Spot Rates. We must develop a model for determining the level of spot rates at various points in time. This we need as an input to the price vector applicable to future points in time.
- Structure of Spot Rates. Given the extensive economies of scale that accrue with the size of tankers it is necessary to analyze the structure of rates and determine the way these economies are divided between the owners and the users of tankers. Depending on the sophistication of the model the rough approximations of a representative spot rate may not be satisfactory, and therefore a structure will be used. We expect that once we develop a model relating cost of operation, level of rates, and structure of rates, we will have the necessary flexibility to choose whatever is appropriate for the main model.
- Range of Fluctuations. As we have already stated, structural differences and fluctuations in rates cause pressure on the "net back" and on the adjustment mechanisms of the producing countries. The wider these differentials and fluctuations around the general price level, the harder it is to administer the price/output system. In order to analyze these pressures and adjustment mechanisms, therefore, we must analyze these fluctuations.

A subsequent step of the research will be concerned with determining the relationships between the structure of spot rates and the structure of time charter rates. This will enable us to determine the relevant cost for transportation in the long-run. Besides the short-run considerations, we wish to analyze the behavior of time charter rates because on the average over 80% of all oil transported is carried on vessels owned by oil companies or chartered by them on a long-term basis. So although the spot rate at any moment in time is very important in the short-run, its impact diminishes as one tries to plan for the future.

For the determination of "long-term rates" we intend to define a relevant time duration and develop a structure of time-charter rates (for vessels of different sizes). Finally, we would like to develop a model which will enable us to predict what will be the appropriate time charter rate for vessels of different sizes, under different cost and spot-rate assumptions for different time durations and at different points in time.

A third stage of the work in this area will involve a review of the structure of refinery locations, and projection of the consequences of any changes on the cost of transportation of energy and in turn the price of oil.

#### 4.3 Financing

Financing the flow of oil and the recycling of oil producer revenues have been recognized as two of the major problems arising from increased oil prices. In general, both problems have been viewed from the perspective of the consuming countries, i.e., how will they finance their oil imports and how will OPEC investment flows affect their financial markets and economies. However, these problems also may play a major role in the decisions of the producer countries over time.

Financial considerations can be viewed as affecting producers' decisions in three ways. The most direct effect is on how they decide to allocate their wealth (mostly in the form of oil) among the three major alternatives--oil in the ground, domestic consumption and real investment, and external financial assets--in order to establish an optimal time-path of consumption. Since this requires intertemporal optimization, much light can be shed on the problem by employing investment decision models. One clear implication of such models is that the attractiveness of external financial claims in terms of expected appreciation or depreciation in purchasing power, and risk, affects

the time path of consumption decisions and thus may affect pricing and output decisions as well.

Given this framework it is possible to derive some conclusions about the potential effects of the accumulation of financial assets on the pricing of oil in a cartel situation. It can easily be shown that different consumption and investment patterns will result from different assumptions about discount rates--which reflect basic time preferences as well as different degrees of risk aversion--and these will affect the optimal price for oil over time as viewed by different members of the cartel.

The third, although indirect, role of financial considerations is through the mechanism of "recycling." Generally speaking, the term "recycling" refers to (1) an exchange of oil for a financial asset ("bond") or (2) trade in "bonds" among importing countries whereby one importing country accepts the "bonds" of another and pays for the oil with its own "bonds" in order to permit imports by the country unable to finance oil imports with its own "bonds." The result is a larger flow of oil than would otherwise take place. In the two cases, referred to as "primary recycling" and "secondary recycling" the mere existence of financial markets as well as the "depth" of the markets in terms of securities' characteristics are of great importance.

This part of the research places major emphasis on these issues, focusing on the nature and volume of available financial assets in the world's capital markets as a potential influence on the pricing and output decisions. To some extent, the relationship of the financial study to the large simulation and the optimizing models of cartel behavior is similar to that of the transport and refining study. The overall simulation results and the optimal output paths in the cartel models are determined without reference to physical

constraints imposed by transport or to "capacity" constraints in financial markets. These latter "constraints" can be viewed as resulting both from non-OPEC behavior, i.e., restrictions on OPEC investment, and from OPEC behavior, i.e., insistence on investing in only a very narrow range of assets. The results of the two major modeling efforts then are checked in a market clearing context to see if they are rendered infeasible by the constraints.

Considerable progress has been made in preparation for this cross-checking of the major models with potential financial constraints. Current OPEC investment patterns, policies toward OPEC investment, and special proposals for OPEC funds have been surveyed. Projections of OPEC build-ups have been monitored and summarized (although the major models of the M.I.T. study are expected to provide better projections). Finally, various measures of the volume as well as the specific risk-return attributes of available assets have been studied in some detail.

## 5. REVISED WORK SCHEDULE

Table 3 presents a revision of the work plan originally presented in Supplement No. 2 (dated December 20, 1974) to the research proposal to NSF. The bulk of the table is essentially the same as that presented earlier, except all tasks are shifted one month to account for the fact that the December 20 table anticipated a February start, and the project did not receive NSF support until March. Other changes from the original work plan are described in a set of notes to Table 3, with references at the appropriate points in the table. The table notes also provide an indication of the progress on tasks that have not changed since the original table was prepared.

Several points that were discussed in the text above are evident in the revised work plan. Earlier, we had a category of activities called "special studies;" in this report these tasks fall in the area of study of "market clearing processes." Progress in these areas is about as expected. In addition, a set of tasks on financial aspects has been added. Work on data preparation for supply studies is proceeding about as planned. However, on the basis of the first six months work, it is possible to write a more clear task statement for the modeling aspect of the supply analysis. This is included in the table.

As the table shows, the demand work has fallen behind the original schedule, due to difficulties in data collection. The problems encountered in this area are discussed in Section 2. The development of the overall simulation framework is proceeding satisfactorily, although it appears that the full integration of the supply and demand analyses into simulation model will take place two or three months later in the project period than originally anticipated.

Finally, the table makes clear that this plan covers only the first 18 months of a longer term effort. At several points in the text, reference is made to tasks that logically come only after completion of early stages of the research, or that do not appear feasible within the project resources (expertise and manpower as well as funds) that are available in the current grant period. Though the planning of the next major phase of the work (beyond August 1976) has been carried out in less detail than the first 18 months, Table 3 shows the areas we believe will prove important points of focus for extension and improvement of the analysis.

### TABLE 3. Work Plan For The First Year

[illegible]

TABLE 3 (Continued)

Task	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
<u>Special Studies (continued)</u>																		
1.4 Refinery Sector																		
- Review and evaluation of available data and models of the refinery sector. Study of emerging patterns of ownership and location.																		
- Analysis of desirable additions to the first-stage or "bathtub" model to discriminate crude and products.																		
- Develop and begin implementation of additions to discriminate crude and products.																		
1.5 Financial Studies (8)																		
- Survey and analysis of the relevant financial aspects of the world oil market.																		
- Survey and analysis of forecasts of projected oil revenues and of proposals to alleviate associated problems. Survey and analysis of OPEC investment patterns.																		
- Development of a model of oil trade and recycling of oil revenues.																		
- Preliminary design of an investment behavior model for owners of exhaustible resources.																		
- Explore and develop methods to introduce financial consideration (different time and risk preferences) into the analysis of cartel pricing policy.																		
<u>Supply Studies</u>																		
2.1 Data Preparation (6)																		
- Preparation of preliminary supply data, from readily available sources, for preliminary simulation																		



TABLE 3 (Continued)

[illegible]

TABLE 3 (Continued)

		M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Demand Studies	Task																		
3.1	Work on alternative theoretical specifications of demand functions. Consider compatibility with overall model framework. Also consider where modifications to specifications may be possible if made necessary by data limitations or by structure of overall model.																		
3.2	Survey potential data sources. Begin construction of data base, including organization of computer framework (i.e., TROLL). Come to some conclusions about limitations of data.																		
3.3	Modify demand specifications in response to data limitations. Obtain initial approximations to demand functions for use in testing overall model structure.																		
3.4	Construct data base on TROLL system. Check and verify data. Evaluate constraints and limitations imposed on demand estimation by missing data points, data errors, etc. <ul style="list-style-type: none"> <li>- Residential demand</li> <li>- Industrial demand</li> <li>- Other sectors</li> </ul>																		
3.5	Estimate first round of demand functions. Evaluate estimates and test demand functions both individually and in the context of overall model. <ul style="list-style-type: none"> <li>- Residential demand</li> <li>- Industrial demand</li> <li>- Other sectors</li> </ul>																		

TABLE 3 (Continued)

Task	M A M J J A S O N D J F M A M J J A											
<u>Demand Studies (continued)</u>												
3.6 Improve demand functions, including respecification and re-estimation where necessary. Install revised demand functions in overall model.						(5)						
3.7 Write working paper describing first-year demand study, and discussing implications of demand results for oil/energy policy and for likely evolution of world oil market. Decide where further work to improve demand is necessary.						(5)						
3.8 Estimate second-stage demand functions, and continue update and improvement of inputs to the second-stage simulation model.											(8)	
<u>Development of Simulation Model</u>												
4.1 Formulate and program the first-stage of the "bathtub" version of the simulation model (i.e., no refinery activities, simplified representation of transport cost, unified world market).						(2)						
4.2 First runs with first-stage model framework and rough supply and demand functions. Decisions regarding possible division into regional market areas.								(2)				
4.3 Development of full details of the model framework to be developed in the first year and introduction of demand and supply data resulting from tasks 2.3 and 3.5.								(4)				

TABLE 3 (Continued)

Task	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Development of Simulation Model (continued)																		
4.4 Analysis of the market using full range of results to date. Decide specification of second-stage model development (e.g., transportation, differentiation of refinery products, refinery operations, etc.).																		
4.5 Develop second-stage model framework, introducing the results of studies of the transport sector (tasks 1.2 and 1.3).																		(8)
4.6 Analysis of the market using the framework developed in task 4.5 and the continuing results of other tasks.																		(8)
4.7 Begin work on the introduction of refining activities into the model framework.																		(8)

NOTES FOR TABLE 3

- (1) Task completed and results integrated with other parts of the research program.
- (2) Task completed and discussion paper available.
- (3) Task completed and discussion paper in preparation.
- (4) Work on task proceeding as anticipated.
- (5) Task description remains essentially the same, but timing revised to that shown by dotted line.
- (6) Task redefined; revised text shown here. For original see see Supplement No. 2 to the research proposal, dated December 20, 1974.
- (7) New task, partially supported by M.I.T. Energy Laboratory Internal Funds.
- (8) Continuation of research in this area will be a major focus of work in any continuation beyond August 1976.

REFERENCES

1. Chase Manhattan Bank, Capital Investments of the World Petroleum Industry (Annual).
2. Eckbo, P.L., "OPEC and the Experience of Previous International Commodity Cartels," M.I.T. Energy Laboratory Working Paper No. 75-008WP, August 1975.
3. Eckbo, P.L., "The International Petroleum Market--Some Behavioral Options," Doctoral Thesis, Massachusetts Institute of Technology, September 1975.
4. Houthakker, H.S., "New Evidence on Demand Elasticities," Econometrica, April 1965 (Vol. 33, No. 2).
5. Jorgenson, D.W., "Consumer Demand For Energy," Harvard Institute For Economic Research, Discussion Paper 386, November 1974.
6. Kaufman, G., Y. Balcer, and D. Kruyt, "A Probabilistic Model of Oil and Gas Di-covery," in Studies in Geology, Vol. 1, American Association of Petroleum Geologists (forthcoming 1975).
7. Lehman, H.S., J.W. Devanney, and J.B. Lassiter, "The M.I.T. Offshore Development Model" (unpublished working paper), September 1, 1974.
8. OECD, Energy Prospects to 1985, Paris, 1974.